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URANIUM ALLOY DEVELOPMENT

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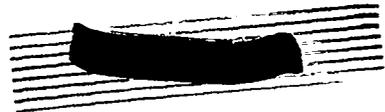
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**UNCLASSIFIED**ABSTRACT

Alloys of uranium were made containing 5 percent by weight of each of the following elements: iron, nickel, cobalt, tungsten, copper, molybdenum, chromium, silver, columbium, manganese, tantalum, platinum, titanium, zirconium, and thorium. Of the alloys investigated, uranium with about 5 percent molybdenum appeared to offer most promise, as it was susceptible to hardening by heat treatment. The microstructure indicated the presence of relatively extensive solubility and indicates that a considerable improvement of strength by heat treatment should be possible. Preliminary experiments on the preparation of one gram heats of uranium were not successful.

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## URANIUM ALLOY DEVELOPMENT

**UNCLASSIFIED**INTRODUCTION

This report describes the first stages of an investigation aimed at the development of uranium alloys with yield strengths greater than that of the pure metal. Such alloys, if not possessed of undesirable nuclear properties, should be of use in many structural applications of the metal. The method of attack was to study the microstructure and the change of hardness accompanying heat treatment of alloys with a wide range of elements. Those alloy systems which show evidences of sufficient solubility or whose hardness is high and modified by heat treatment will be selected for more detailed study.

PREPARATION OF THE ALLOYS

Alloys were made in approximately 250 g amounts by placing the charges in beryllium oxide crucible heated by a graphite crucible in a vacuum induction furnace. A maximum temperature of 1300° - 1350° C. was used, and the heats were held for about 15 minutes at this temperature. The ingot was allowed to freeze in the crucible, and about 20 minutes were required before the alloys cooled to a black heat. The ingots were 1 in. in diameter by about 1½ in. long, and were sectioned for hardness tests and microscopic examination. While a small pipe was usually formed near the center of the ingot, this caused no difficulty in the tests.

The vacuum was of the order of 1 to 5 microns during melting, and while some oxidation occurred, no difficulty was experienced in obtaining consolidated and clean melts. For a rapid preliminary survey, the first series of alloys was made with additions of 5 percent by weight of some more promising elements. A few alloys with other amounts were later made. The type or

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source of the alloying metals is given in Table I. ~~Most of the alloying~~  
elements were added in the form of small lumps; columbium, molybdenum, tantalum, and thorium were added as powders, titanium and zirconium as hydride powders which dissociated before melting. All the additions were charged with the uranium into the cold crucible before evacuating and heating. Practically all the silver was lost by volatilization. Similar loss of manganese was prevented by use of an argon atmosphere instead of a vacuum. The thorium powder used was apparently not wet or dissolved by the molten uranium and was oxidized when the heat was examined after removal from the furnace. In a few cases partial liquid miscibility was encountered, but with the exception of these and the uranium-columbium heat, no obvious segregation was observed in any of the melts. However, chemical analysis of top and bottom sections of many ingots showed considerable differences in composition, probably largely a result of insufficient stirring during melting to overcome the large difference of density of the components.

The nominal and actual compositions of the heats are shown in Table II, together with the hardness after various heat treatments.

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TABLE I

TYPE OR SOURCE OF ALLOYING METALS USED IN MAKING THE ALLOYS

<u>Alloying Metal</u>	<u>Type or Source</u>
Uranium	Extruded rod #RU-480
Iron	Armco Iron sheet
Nickel	Electrolytic cathode
Cobalt	Rondelles
Tungsten	0.05 in. wire
Copper	Shot (Baker Chemical Company)
Molybdenum	Molybdenum bar
Chromium	Electrolytic (Union Carbide)
Silver	Electrolytic crystals (Anaconda)
Columbium	Powder (probably thermite) (Fairmount Chemical Company)
Manganese	Electrolytic
Tantalum	Powder (Fansteel Metallurgical Corp.)
Platinum	0.005 in. wire
Titanium	Titanium hydride powder (Metal Hydrides)
Zirconium	Zirconium hydride powder (Metal Hydrides)
Thorium	Powder (Metal Hydrides)

TABLE II. HARDNESS OF URANIUM ALLOYS AFTER HEAT TREATMENT

Sample No.	Composition Intended, Balance Uranium			Composition by Analysis Weight %		Rockwell A Hardness						
	Element	Atomic %	Weight %	Upper section used in tests	Lower section used in tests	As Cast	Quenched After 2 hr. at 900° C.	Quenched 300°C	Quenched 400°C	Quenched and reheated 2 hr. successively at 500°C	600°C	700°C
2001	U	100	100		.014 Fe	49	57	56	58	58	52	57
2002	Fe	18.3	5 (a)	5.00 Fe (2)	3.26 Fe	--	--	--	--	--	--	--
2003	Ni	17.6	5 (b)	5.7 Ni	2.1 Ni	67	--	--	--	--	--	--
2004	W	6.4	5	1.2 W	1.5 W	61	59	60	60	52	64	59
2005	Co	17.5	5(a)	5.3 Co	4.21 Co	--	--	--	--	--	--	--
2012	Cu	16.5	5 (c)	1.4 Cu	1.5 Cu	56	59	60	60	58	58	58
2013	Mo	11.6	5	2.8 Mo	2.6 Mo	67	63	75	77	73	57	67
2014	Cr	19.4	5(d)	3.2 Cr	1.5 Cr	64	72(800°)	72	71	68	60	67
2015	Ag	10.4	5(e)	trace Ag	.09 Ag	54	54	58	57	56	56	57
2016	Cb	11.9	5	5.4 Cb	4.5 Cb	67	67	71	73	75	70	71
2021	Mn	18.6	5 (b)	8.8 Mn	---	65	--	--	--	--	--	--
2022	Ta	6.5	5	7.7 Ta	1.5 Ta	63	70	70	70	70	67	68
2023	Pt	6.0	5	5.20 Pt	5.32 Pt	65	72	74	73	70	67	71
2024	Ti	20.7	5 (c)	1.4 Ti	1.4 Ti	69	70	73	--	--	--	--
2046	Zr	12.1	5 (c)	1.16 Zr	1.05 Zr	60	63	64	--	--	--	--
2047	O (1)	8.8	.6 (f)	---	---	--	--	--	--	--	--	--
2056	Mo	15.7	7	6.88 Mo	3.89 Mo	69	60	76	--	--	--	--
2058	Mo	7.1	3	3.83 Mo	2.01 Mo	68	65	75	--	--	--	--
2062	Th	5.1	5 (f)	---	---	56	59	--	--	--	--	--
2072	Ti	2.4	0.5	---	---	53	58	--	--	--	--	--
2073	Th	5.1	5 (f)	---	---	53	59	--	--	--	--	--
2072	Ti	1.0	0.2	---	---	59	58	--	--	--	--	--

- (a) Fractured during sawing
- (b) Melted at 800° C. and 900° C.
- (c) Forms two liquid layers
- (d) Melted at 900° C., heat treated samples were quenched from 800°C.

- (e) Alloy element lost by volatilization
- (f) Alloy element not dissolved by melt
- (1) Added as UO<sub>2</sub> (5% by weight)
- (2) 6.90% in the middle section

EXPERIMENTAL RESULTSHARDNESS TESTS

To investigate the response of the alloys to heat treatment and to learn if alloys hardenable by transformation, precipitation, or otherwise could be obtained, the alloys were given a 2 hour annealing at 900° C., followed by water quenching, and then were re-heated for 2-hour periods successively at temperatures of 300° C. to 700° C. in 100° steps. The Rockwell A hardness of each sample was measured after each stage of heat treatment. The first few alloys (through 2012) were heat treated at 900° C. in a tank hydrogen atmosphere and were re-heat treated in air, protected by wrapping in copper foil. While this procedure was reasonably satisfactory, less scale formation was obtained when conducting all heat treatments in a vacuum furnace that was later constructed.

It will be noted that both the uranium-molybdenum and the uranium-columbium alloys show hardness improvement with heat treatment. The uranium-molybdenum alloy in particular is interesting because not only does it attain the highest hardness, but also shows the greatest improvement in hardness by heat treatment. The molybdenum alloy in the hardest state (Rockwell A 77) showed some malleability as a fragment could be peened with a hammer. A section of the ingot of the 5 percent alloy was quenched from 900° C. and re-heated at 400° C. for various periods of time. The results are shown in Table III.\* (See note on following page.)

TABLE III. ROCKWELL A HARDNESS OF URANIUM-5PERCENT MOLYBDENUM ALLOY  
AFTER RE-HEATING FOR VARIOUS PERIODS AT 400° C.

As quenched from 900° C.	Reheated at 400° C. for					
	1 hr.	2 hr.	4 hr.	8 hr.	16 hr.	32 hr.
68	77	78	78	77	76	75

There is little difference in hardness after heating times of one to sixteen hours, though the expected tendency to soften on prolonged heating is seen. Times shorter than one hour are to be investigated.

.....

\* Note added 12/3/43: The following table summarizes the results of some compression tests completed too late for inclusion in the body of this report.

MECHANICAL PROPERTIES OF URANIUM AND URANIUM-MOLYBDENUM ALLOYS

<u>Material</u>	<u>Condition</u>	<u>Yield Strength, 0.2% Offset, lbs/sq. in.</u>	<u>Maximum Stress on compression lbs/sq. in.</u>	<u>Rockwell A Hardness</u>
Pure Uranium (a)	Cast	27,500	(c)	(50)
Pure Uranium (b)	Cast	29,000	(c)	(50)
Nominal 5% Mo alloy	HT	207,000	280,000	76
Nominal 5% Mo alloy	HT	206,000	287,000	76
Nominal 3% Mo alloy	HT	-----	193,000	-----

- (a) Extruded rod, remelted in BeO crucibles and cast in  $\frac{1}{2}$  in. diameter graphite mold.
- (b) Part of 3 in. diameter casting made for ordnance, graphite crucible and mold.
- (c) Flattened without fracture.
- (HT) Annealed 2 hours 900° C., quenched, reheated 2 hours 300° C.

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As indicated in the table, the uranium-nickel, uranium-manganese melted on heat treatment, both at 900° C. and 800° C., while the uranium-chromium alloy melted at 900° C., but not at 800° C., though it cracked badly on quenching from this temperature. The uranium-platinum alloy was so brittle as quenched that a light tap with a hammer was enough to fracture it. The uranium-iron and uranium-cobalt were too brittle as cast to be saved, and were excluded from further work.

Two liquid layers were evident in the uranium-copper, uranium-titanium, and uranium-zirconium alloys. The percent of the lighter alloy-rich material occupied approximately 10 percent, 40 percent, and 20 percent by volume in these three alloys, respectively.

Because of very marked segregation of the uranium-columbium alloy, the hardness results are doubtful, although there was remarkably little difference in hardness between the various areas tested. The columbium was apparently only slightly soluble and "segregation" is actually caused by aggregations of columbium powder irregularly distributed throughout the melt.

After the first failure with the thorium powder addition, two heats were made adding compacted pellets of the thorium powder to the charge, one green and the other pre-sintered in vacuum. The former method appeared to be somewhat better, but in no case was there evidence of significant solubility or alloying.

The ingots with 5 and 0.5 percent titanium had unusually clean, oxide-free surfaces, particularly on the titanium-rich phase, while in the case of the 0.2 percent titanium heat, the surface was covered with oxide as usual.

ANALYTICAL RESULTS

Analyses of some of the ingots (made by L. M. Berry and E. Maxwell of the chemistry laboratory) are given in Table II. The analyses were made on the sawings made during the cutting of the ingot into samples for hardness and microstructure studies. Although sawing was performed under a copious flood of coolant, the sawings were oxidized to some extent, but not enough seriously to affect the results for minor constituents. The sawings were cut about 1/3 down from the top of the ingot, except where a second figure is reported in Table II. The additional figures were obtained from samples cut near the bottom of the ingot; in no case was the extreme upper portion of the ingot used for hardness tests.

In several cases the upper samples contained higher percentages of the alloying elements than the lower part of the ingot, even when separation into two liquids did not occur. This may be due to incomplete mixing of the molten alloys (the melts were not stirred, and electromagnetic stirring was extremely small since the metal was shielded by the graphite crucible), or perhaps the composition difference is due to gravity segregation during solidification, which was slow enough to allow separation of a light solid constituent if not enmeshed during crystallization. It is significant that no segregation occurred in the platinum alloy.

The worst vertical segregation in the absence of liquid immiscibility was found in the uranium-nickel ingot, followed by the iron and cobalt alloys. Fortunately, these systems appear to be only of academic interest as their mechanical properties were found to be very poor.

The liquid-segregated top of the uranium-titanium ingot analyzed 16.6 percent titanium while just below it analyzed 2.8 percent titanium, but probably contained some of the lighter liquid. The top of the uranium-zirconium ingot contained 25.5 percent zirconium.

METALLOGRAPHYPOLISHING AND ETCHING

Electrolytic polishing, using a solution containing 8 parts of phosphoric acid, 8 parts of ethylene glycol, and 13 parts of ethyl alcohol, was used after polishing mechanically as far as 600 grain carborundum on a billiard cloth wheel. Between 6-7 volts with a current of about 40 milliamperes on a specimen of about 1 sq. cm. area gave a reasonably good polish in about 30 minutes. A semicylindrical stainless steel cathode about 3 in. in diameter was employed. The specimen, mounted in bakelite, lay face up on the bottom of the beaker. Contact with it was made by a platinum wire pressed against its surface.

Electrolytic etching, using a 10 percent oxalic acid-water solution was used in all cases. About 100 milliamperes at 2 volts gave satisfactory results in 1-3 minutes.

Photomicrographs of most of the alloys of Table II in the as-cast and as-quenched condition have been prepared. In many cases the structure as polished as well as after etching is given since detail is sometimes lost on etching. All photomicrographs were taken at a point represented by the "upper" analysis of Table II, except for Figs. 4, 6, 34, and 35 (Negatives no. 2002-0, 2005-0, 2004-Q0, 2024-1, 2046-2).

PURE URANIUM, FIGS. 1-3

Fig. 1 shows the characteristic structure of commercially pure vacuum melted uranium with copious cubical inclusion of carbides (etching dark), the "eutectic" patches which may be a uranium-uranium-oxide eutectic. Also visible are mechanical twins which are often seen in the alloys, and probably result from sawing, grinding, or other maltreatment of the surface. A similar sample, quenched from 900° C. (Fig. 2), shows many fewer carbide particles, indicating some solid solution of carbon at this temperature and a

well developed network of some phase precipitating at "sub-grain boundaries." Fig. 3 shows a transverse section of the extruded rod. It is very similar to Fig. 2 except that the particles suspected to be carbide are more numerous, and are not of cubic shape, presumably because of the thermal and mechanical history of the specimen.

#### URANIUM-IRON, FIG. 4

The 5 percent uranium-iron alloy is shown in Fig. 4, unetched. Etching brought out no further detail, but tended to obscure the structure somewhat. Apparently the matrix is an intermetallic compound judging from the extreme brittleness of the alloy, and the dendrites are probably primary uranium-rich solid solution.

#### URANIUM-NICKEL, FIG. 5

The structure shown appears to be that of primary uranium-rich dendrites coated with a reaction rim, indicating a peritectic with final solidification as a eutectic. The presence of the eutectic fits in well with the observation that the alloy partially melted or annealed at 800° C.

#### URANIUM-COBALT, FIG. 6

This alloy is structurally identical to uranium-iron.

#### URANIUM-TUNGSTEN, FIGS. 7, 8

The structure of the cast alloy is practically identical with that of the pure metal except for the presence of cubes, of a tungsten-rich phase, probably nearly pure tungsten. The tungsten had been added to the charge as wire. Several pieces of it were still present undissolved in the final ingot, but at least some had gone into solution at the melting temperature and had solidified before the uranium. The cubes of tungsten-rich constituent were unaffected by electrolytic polishing or etching, evidently being electronegative to uranium. The quenched sample shows a rather copious amount of a finely divided phase which may be some tungsten separating from solid solution because of an inade-

quate quench. The carbide phase seems to exist in the same form as in the original uranium sample.

URANIUM-COPPER, FIGS. 9, 10

The copper-rich portion at the top of the ingot was not examined, but the photomicrographs show the structure of the bulk of the ingot. The globules shown in both pictures are supposedly a copper-rich phase, but it is hard to account for their distribution by any common solidification mechanism. Annealing at 900° C. produced no visible change in structure. Note that the carbide phase in this alloy crystallizes in the form of crosses.

URANIUM-MOLYBDENUM, FIGS. 11-14

In the as-cast condition, the 3 percent and 5 percent alloys (Figs. 11 and 13) show a somewhat poorly resolved duplex structure not unlike a troostitic steel and clearly resulting from transformation and decomposition of a high temperature phase, for there is evidence of related orientation difference in grains resulting from larger ones, and revealed by the distribution of the finely divided precipitated phase. The sample of 5 percent molybdenum quenched from 900° C. shows nearly everything in solid solution, although there are many small inclusions of carbide or some metallic constituent which have not completely dissolved. Apparently a eutectoid is formed which, when decomposed at a suitable temperature level, can cause considerable hardening throughout the alloy. The 7 percent molybdenum alloy shows what appears to be "discontinuous precipitation," the dark etching areas being areas that have decomposed and probably recrystallized and which are evidently growing into the white etching areas of probably untransformed gamma.

URANIUM-CHROMIUM, FIGS. 15, 16

The structure of the cast alloy is difficult to explain. What seem to be primary dendrites have some constituent like a eutectic in them. They are

surronded by a mass of normal eutectic structure and distribution. After quenching from 900° C. the chromium-rich phase of the eutectic has spheroidized while the main constituent shows uniform markings, indicating some solid solution and decomposition during quenching.

#### URANIUM-SILVER, FIGS. 17-20

The cast structure shows (besides the characteristic cubic carbides) small patches of a silver-rich phase, exaggerated in size by etching. As usual, the carbides are taken into solution after quenching from 900° C. (Figs. 18, 20). The unetched samples give a better idea of the amount of the silver phase. Some of the small inclusions in Fig. 20 are incompletely dissolved carbide. Very little silver had remained in the alloy.

#### URANIUM-COLUMBIUM, FIGS. 21-24

This alloy showed three distinct zones because of segregation. The largest amount in the cast sample appears to be a two phase "martensitic" structure (Fig. 21). The martensitic appearance was more clearly defined after quenching from 900° C. (Fig. 22). Both before and after quenching, another zone was visible which had no martensitic markings. An intermediate zone (Fig. 24) occurred in the quenched sample only.

#### URANIUM-MANGANESE, FIGS. 25, 26

The as-cast structure showed a primary light etching phase, surrounded by a eutectic. Some precipitate is visible in the primary phase at higher magnification (Fig. 26).

#### TANTALUM-URANIUM, FIGS. 27-30

Particles of an undissolved phase, probably tantalum, were distributed rather irregularly throughout the sample. Great difficulty was encountered in obtaining a satisfactory polish. It is possible that the second phase dissolved on heat treatment at 900° C., but its nonuniform distribution may account for

the lack of particles in Fig. 28. No significant hardness changes occurred, but microstructural evidence of precipitation in the quenched samples shows that some solution had occurred.

#### URANIUM-PLATINUM, FIGS. 31-33

The as-cast alloy appears to consist of two phases, one as a finely divided precipitate from transformed high temperature phase. The thin black bars are either a platinum bearing phase or carbide. The quenched sample shows chiefly a single phase structure with considerable finely divided constituent.

#### URANIUM-TITANIUM, FIG. 34

The structure shown in Fig. 34 is characteristic of the uranium rich part of the ingot, and appears to consist of two phases, rather finely divided with a suggestion of a martensitic appearance.

#### URANIUM-ZIRCONIUM, FIG. 35

The as-cast structure of the zirconium rich part of the ingot consists of two phases, very finely divided, in the usual arrangement reminiscent of partially decomposed martensite.

#### URANIUM-THORIUM, FIGS. 36, 37

A constituent, probably a thorium bearing eutectic, appears in the grain boundaries. The carbide particles, in usual form, are more evident in the unetched specimen.

#### GENERAL DISCUSSION OF STRUCTURES

It is obvious from the photomicrographs that addition of most of the elements studied causes the formation of intermetallic compounds with uranium, and solid solutions of any useful extent exist only in few cases. It is impossible to retain the high temperature forms of uranium by quenching, but it is to be expected that additions of certain alloying elements will go into

solution in the gamma phase, and change both the temperature and rate at which it transforms on cooling. The pseudo-martensitic structure visible in several of the photomicrographs and containing a finely divided precipitate with definite evidence of having been deposited from one phase or both of a Widmanstätten structure, seems to result from the combined change of crystal structure on passing from gamma to alpha (with or without intermediate beta formation) followed by precipitation of a phase containing the second component, which is less soluble in alpha than in gamma. The analogy with the iron-carbon diagram is apparently quite close, although the hardnesses obtainable are not commensurate, probably because substitutional rather than interstitial solutions are involved. The martensite-like structure is observed clearly in the alloys with molybdenum, columbium, tantalum, platinum, titanium, and possibly chromium. It can be assumed that in each case sufficient solubility of the element has occurred to leave sufficient differences of composition to make the results of the allotropic transformation visible on etching. However, only in the case of molybdenum is the amount of solubility even nearly as high as the amount of element added, 5 percent by weight. Further tests with smaller percentages of the above elements and with more careful quenching are planned.

#### EXPERIMENTS WITH ONE GRAM MELTS

Several one gram heats of uranium were made in the vacuum induction furnace, using 3 or 4 short lengths of 0.04 in. uranium wire. The vacuum was about one micron during melting. The crucibles used were of zirconia, and had internal dimensions of about 4 mm. diameter at the bottom, 6 mm. diameter at the top, and about 10 mm. high. Oxide skin and surface tension prevented the molten metal from flowing into a satisfactory ingot. At best only about half the ingot could be used for hardness or compression tests, etc.

The addition of about 0.5 percent titanium hydride did not greatly aid consolidation.

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FIGURE WORK

It is planned to continue the investigation of uranium-molybdenum alloys with respect to finding the optimum composition and heat treatment. This will involve a preliminary investigation of the constitution diagram in the region of 1-10 percent molybdenum or higher, and compression tests on selected compositions and heat treatments.

The work on one gram heats will be eventually extended to cover new alloy investigations after a new vacuum furnace especially designed for these small heats is built. This will include a method of vibrating the melt to aid consolidation.



Fig. 1. Vacuum Melted Uranium, as cast.  
Etched electrolytically in 10% oxalic acid.

2001-0

x 100

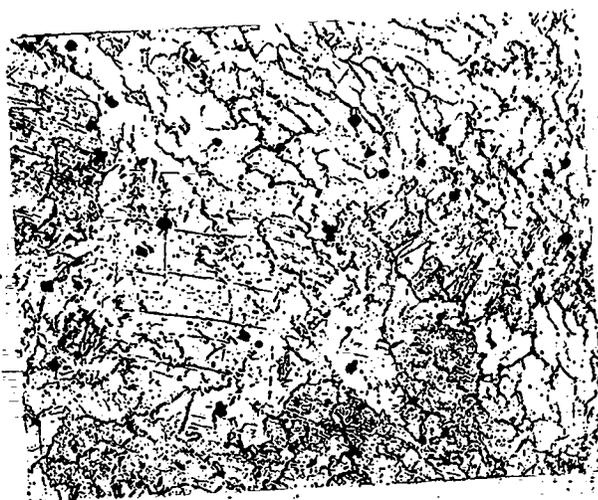


Fig. 2. Vacuum Melted Uranium,  
quenched 900° C.  
Etched electrolytically in 10% oxalic acid.

2001-Q-0

x 100

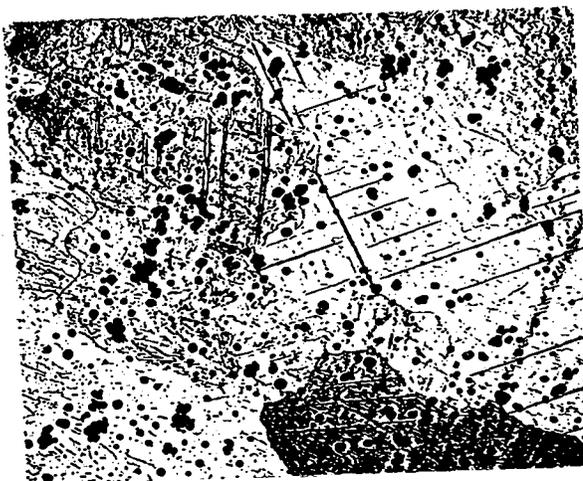


Fig. 3. Extruded Uranium Rod, RU480,  
Transverse section.  
Etched electrolytically in 10% oxalic acid.

2045-1

x 250

Note: All figure captions give nominal compositions; actual compositions are often considerably lower.

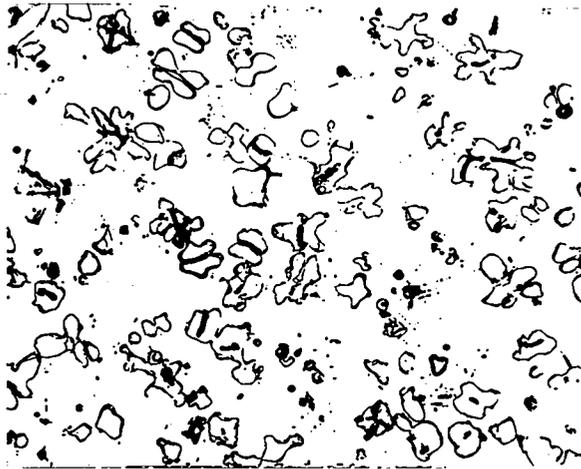


Fig. 4. 5 Fe-U Alloy, as cast.  
Not etched.

2002-0

x 100

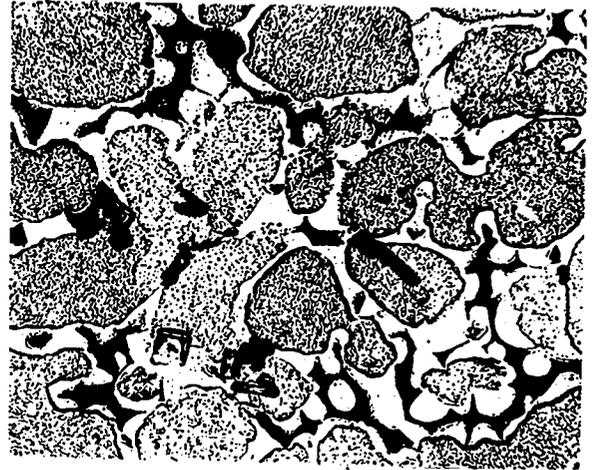


Fig. 5. 5 Ni-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2003-3

x 100

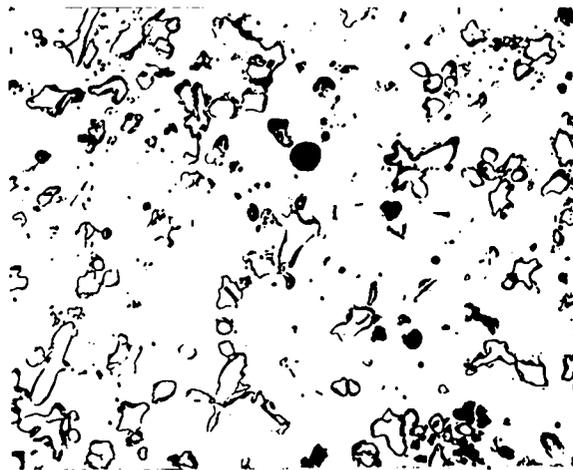


Fig. 6. Co-U Alloy, as cast  
Not etched.

2005-0

x 100

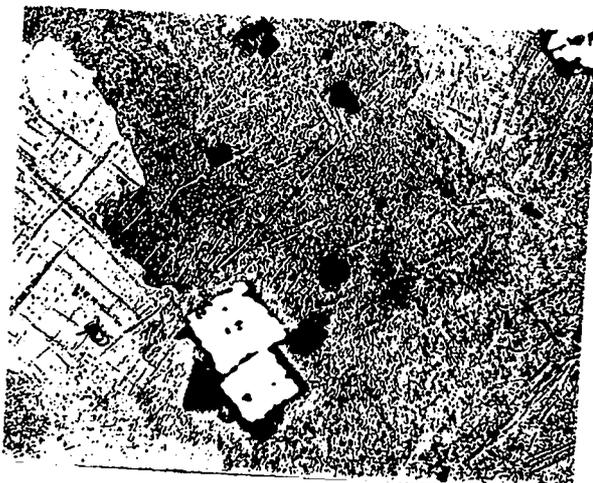


Fig. 7. 5 W-U Alloy, at cast  
Etched electrolytically in 10% oxalic  
acid.

2004-3

x 250



Fig. 8. 5 W-U Alloy, as quenched, 900°C.  
Etched electrolytically in 10% oxalic  
acid.

2004-Q-4

x 250

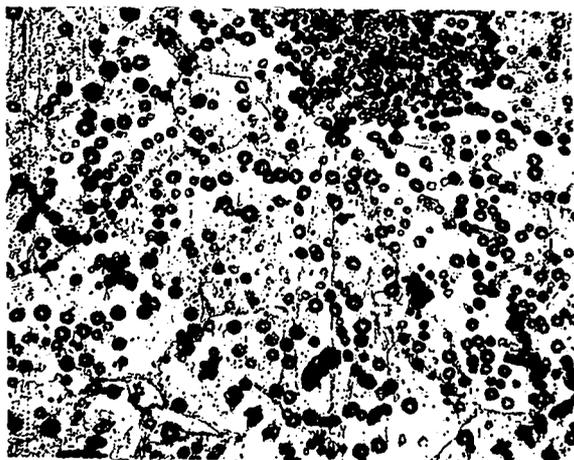


Fig. 9. 5 Cu-U Alloy, as cast.  
Etched electrolytically in 10% oxalic  
acid.

2012-1

x 250

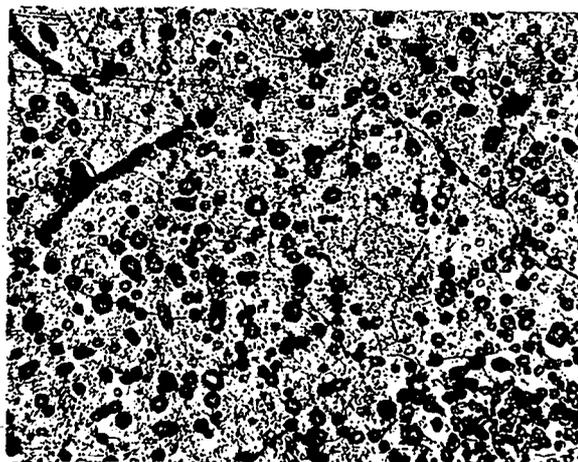


Fig. 10. 5 Cu-U Alloy, as quenched.  
Etched electrolytically in 10% oxalic  
acid.

20012-Q-1

x 250



Fig. 11. 11.8 Mo-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2056-1

x 250

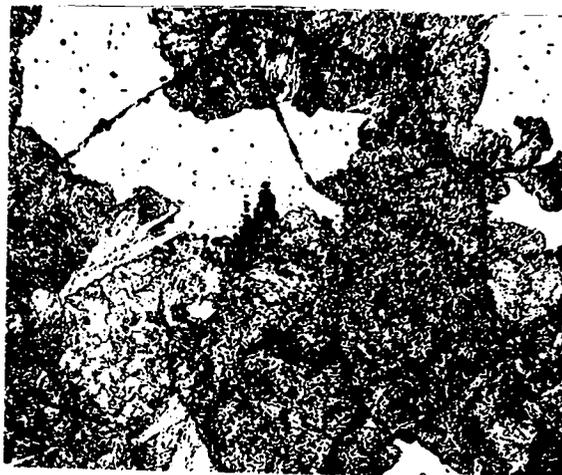


Fig. 12. 7 Mo-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2056-1

x 250



Fig. 13. 5 Mo-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2013-0

x 250

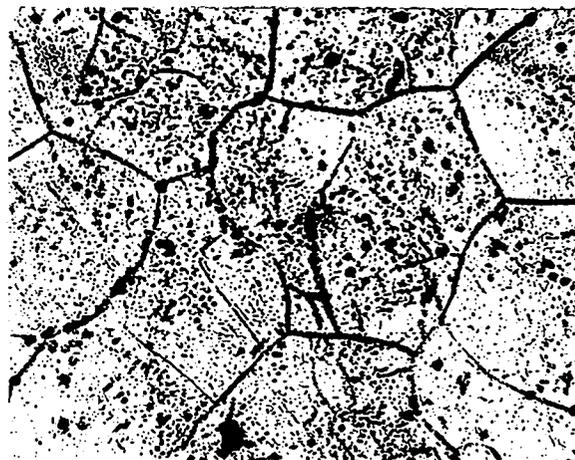


Fig. 14. 5 Mo-U Alloy, as quenched.  
900° C.  
Etched electrolytically in 10% oxalic acid.

2013-Q-0

x 250



Fig. 15. 5 Cr-U Alloy, as cast.  
Etched electrolytically in 10% oxalic  
acid.

201A-0

x 250

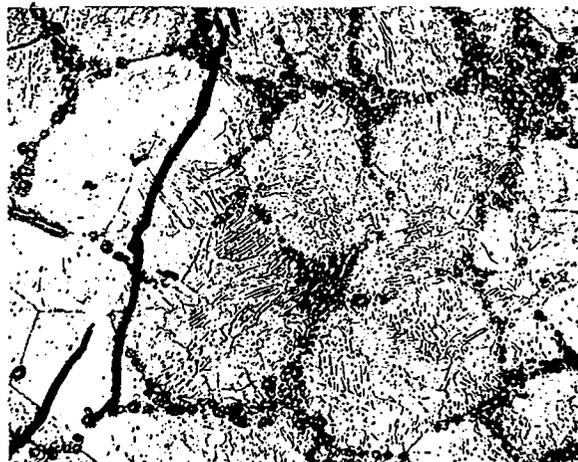


Fig. 16. 5 Cr-U Alloy, as quenched.  
800° C.  
Etched electrolytically in 10% oxalic  
acid.

201A-Q-0

x 250

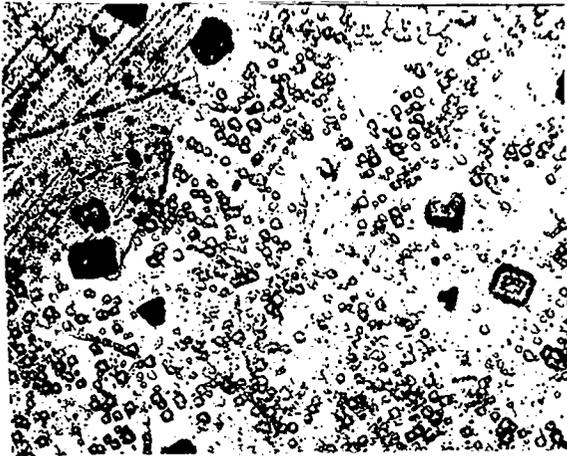


Fig. 17. 5 Ag-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2015-1

x 250



Fig. 18. 5 Ag-U Alloy, as quenched 900° C  
Etched electrolytically in 10% oxalic acid.

2015- Q2

x 250

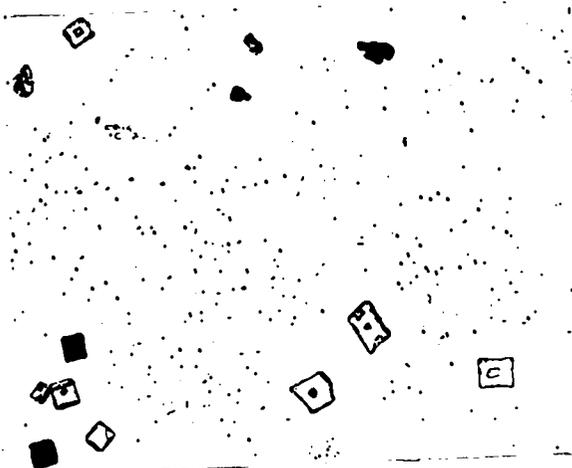


Fig. 19. 5 Ag-U Alloy, as cast.  
Not etched.

2015-3

x 250

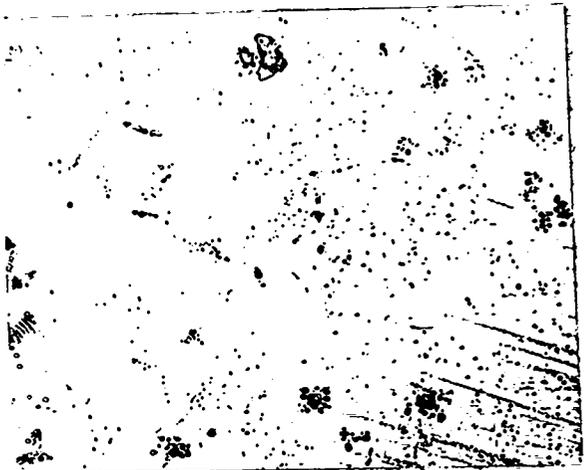


Fig. 20. 5 Ag-U Alloy, as quenched.  
900° C.  
Not etched.

2015-Q1

x 250

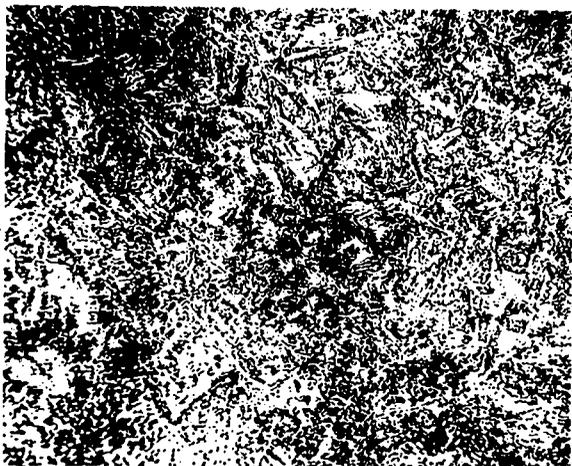


Fig. 21. 5 Cb-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2016-1

x 250

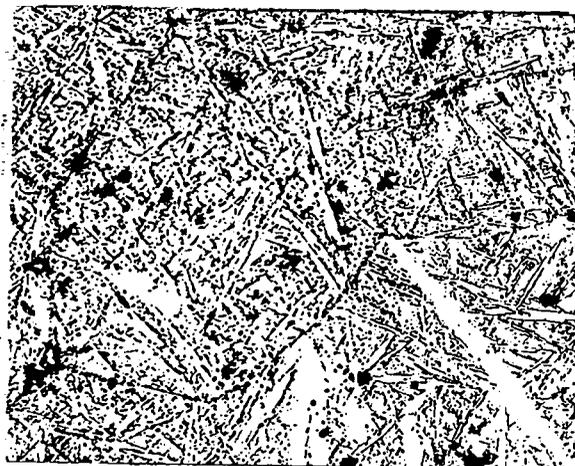


Fig. 22. 5 Cb-U Alloy, as quenched.  
900° C.  
Etched electrolytically in 10% oxalic acid.

2016-Q-0

x 250



Fig. 23. 5 Cb-U Alloy, as quenched.  
900° C. "Intermediate zone."  
Etched electrolytically in 10% oxalic acid.

2016-Q-1

x 250



Fig. 24. 5 Cb-U Alloy, as quenched.  
900° C. "Intermediate" and "Bright Etching" zone.  
Etched electrolytically in 10% oxalic acid.

2016-Q-3

x 250

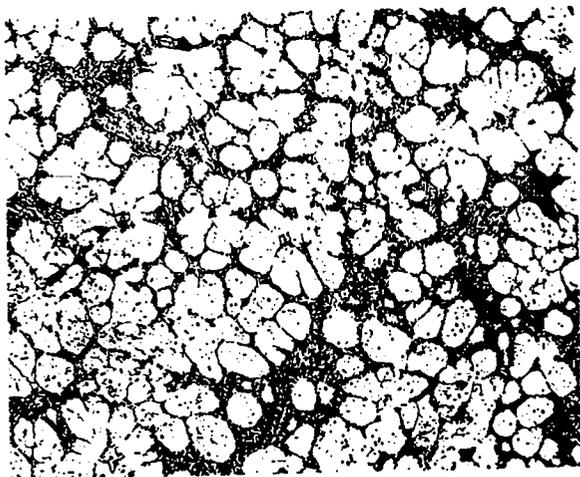


Fig. 25. 5 Ma-U Alloy, as cast.  
Etched electrolytically in 10% oxalic  
acid.

2021-1

x 100

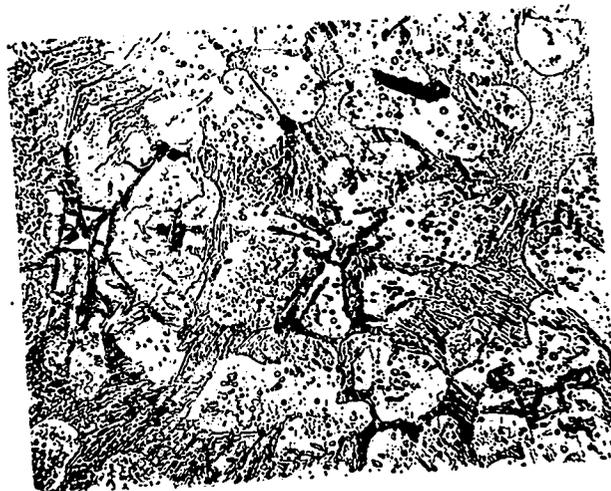


Fig. 26. 5 Ma-U Alloy, as cast.  
Etched electrolytically in 10% oxalic  
acid.

2021-2

x 250

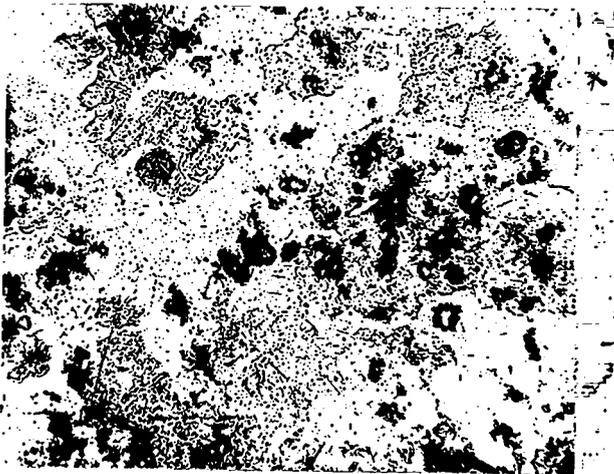


Fig. 27. 5 Ta-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2022-4

x 250

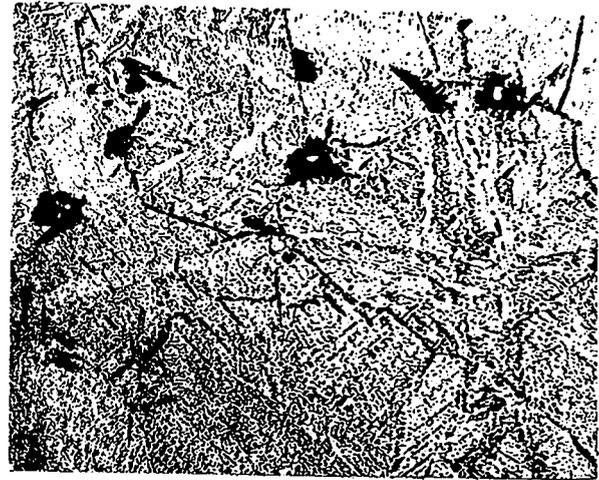


Fig. 28. 5 Ta-U Alloy, as quenched.  
900° C.  
Etched electrolytically in 10% oxalic acid.

2022-Q-3

x 250

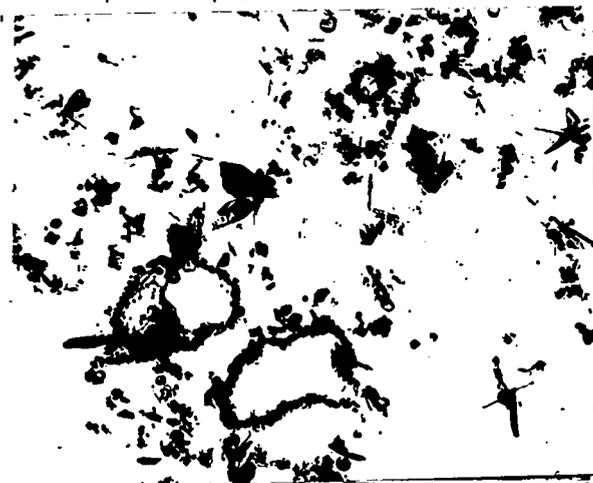


Fig. 29. 5 Ta-U Alloy, as cast.  
Not etched.

2022-2

x 250



Fig. 30. 5 Ta-U Alloy, as quenched.  
900° C.  
Not etched.

2022-Q-2

x 250



Fig. 31. 5 Pt-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2023-2

x 250



Fig. 32. 5 Pt-U Alloy, as cast.  
Not etched.

2023-1

x 250

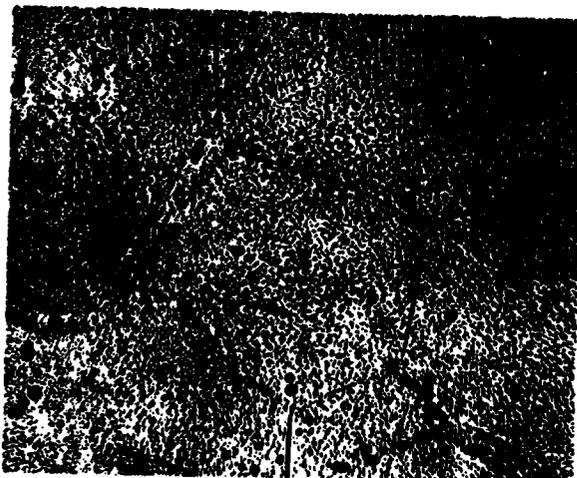


Fig. 33. 5 Pt-U Alloy, as quenched.  
900° C.  
Etched electrolytically in 10% oxalic acid.

2023-3-2

x 250



Fig. 34. 5 Ti-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2021-1

x 250



Fig. 35. 5 Zr-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2046-2

x 250

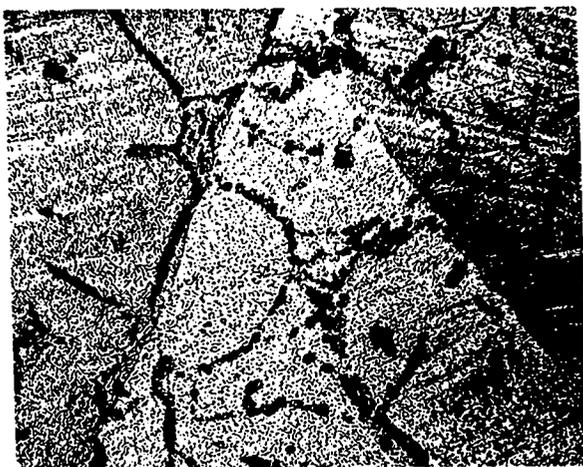


Fig. 36. 5 Th-U Alloy, as cast.  
Etched electrolytically in 10% oxalic acid.

2062-1

x 250



Fig. 37. 5 Th-U Alloy, as cast.  
Not etched.

2062-0

x 250

